Measurement of High-Q^2 Neutral and Charged Current Deep Inelastic e^+p Scattering Cross Sections with a Longitudinally Polarised Positron Beam at HERA

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Abstract. Measurements of the cross sections for neutral current (NC) and charged current (CC) deep inelastic scattering in e^+p collisions with a longitudinally polarised positron beam are presented. The measurements are based on a data sample with an integrated luminosity of 135.48 pb^{-1} for NC and 132 pb^{-1} for CC collected with the ZEUS detector at HERA in 2006 and 2007 at a centre-of-mass energy of 318 GeV. The total CC cross section is presented at positive and negative values of the longitudinal polarization of the positron beams and are used to determine a lower limit on the mass of a hypothetical right-handed W boson.The single differential NC (CC) cross sections $d\sigma/dQ^2$, $d\sigma/dx$ and $d\sigma/dy$ are presented for $Q^2 > 185$ GeV^2 ($Q^2 > 200$ GeV^2). The reduced NC (CC) cross section $\tilde{\sigma}$ is presented. The measurements for both CC and NC agree well with the predictions of the Standard Model (SM).

INTRODUCTION

Deep inelastic scattering (DIS) of leptons off nucleons has proved to be a key tool to understanding the structure of the proton. The neutral current (NC) process at HERA, $e^-(e^+)p \to e^-(e^+)$X, is mediated by the exchange of a γ or Z_0 boson, while the charged current (CC) process, $e^-(e^+)p \to \nu(\bar{\nu})$X, is mediated by the exchange of a $W^{\pm}$ boson.

The NC and CC processes are described by three invariant variables: Q^2, the negative four-momentum squared; x, the Bjorken scaling variable; y, the inelasticity. These variables are related by $Q^2 = sxy$, where s is the centre-of-mass energy squared, neglecting the mass of the proton and electron.

In 2002, HERA was upgraded to provide longitudinally polarised $e^{\pm}$ beams. The polarisation of the $e^{\pm}$ beam is defined as $P_e = (N_R - N_L)/(N_R + N_L)$, where N_R (N_L) is the number of right (left) handed $e^{\pm}$ in the beam.

The NC and CC[1] cross section measurements were made using e^+p data collected in 2006-2007, with a proton beam energy of $E_p = 920$ GeV, and a e^+ beam of $E_e = 27.5$ GeV ($\sqrt{s} = 318$ GeV). The NC (CC) e^+p data set was divided into a 78.8 pb^{-1} (75.8 pb^{-1}) P_e = +32% (P_e = +33%) sample and a 56.7 pb^{-1} (56.0 pb^{-1}) P_e = -36% (P_e = -36%) sample. The values of $\mathscr{L}$ and P_e are not identical due to differences between the NC and CC data selection.

CROSS SECTIONS

The polarised CC reduced cross-section can be written as follows:

$$\tilde{\sigma}_{CC}^{e^{-\{+\}}p} = (1 \pm P_e)\tilde{\sigma}_{CC,P_e=0}^{e^{-\{+\}}p} = x[(u\{\bar{u}\} + c\{\bar{c}\}) + (1-y)^2(\bar{d}\{d\} + \bar{s}\{s\})] \quad (1)$$

where, for example, the PDF $\bar{u}(x,Q^2)$ gives the number density of anti-up quarks for a given x and Q^2. Measurement of the e^+p (e^-p) cross-section is directly sensitive to the d-quark (u-quark) density of the proton. Additionally, the CC cross-section scales linearly with $e^\pm$ beam polarisation.

The NC born-level cross section is given by

$$\frac{d^2\sigma_{NC}^{e^\pm p}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3 - y^2\tilde{F}_L] \quad (2)$$

$$\tilde{\sigma}_{NC}^{e^\pm p} = \frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+}\frac{d^2\sigma_{NC}^{e^+p}}{dxdQ^2} = \tilde{F}_2 \mp \frac{Y_-}{Y_+}x\tilde{F}_3 - \frac{y^2}{Y_+}\tilde{F}_L \quad (3)$$

where $\tilde{\sigma}_{NC}^{e^\pm p}$ is the reduced cross-section, and $Y_\pm = 1 \pm (1-y)^2$. $\tilde{F}_2$, $x\tilde{F}_3$ and $\tilde{F}_L$ are the generalised structure functions, and can be written as a linear combination of the hadronic structure functions, F_2, $F_{2,3}^{\gamma Z}$ and $F_{2,3}^{Z}$, due to γ exchange, $\gamma - Z_0$ interference, and Z_0 exchange respectively. The $x\tilde{F}_3$ structure function becomes significant at high-Q^2 reducing the e^+p cross-section. $\tilde{F}_L$ is expected to contribute only at large y, and be negligible at high-Q^2 and high x.

RESULTS

Unpolarised CC and NC DIS

The CC and NC polarised data can be combined to into an effectively unpolarised, $P_e = 0$, data set after correcting for any residual polarisations. The e^+p CC DIS and $e^\pm p$ NC DIS reduced cross-sections (e^-p NC cross-section published in [2]) as a function of x in fixed Q^2 bins are shown in Fig.1. The SM predictions evaluated using the different PDFs give a good description of the data. The contributions of the PDF combinations $(d+s)$ and $x(\bar{u}+\bar{c})$ to the e^+p CC DIS reduced cross-section are presented in Fig. 1 (left).

The significant difference between the NC e^+p and e^-p cross-sections observed at high-Q^2 due to the $x\tilde{F}_3$ contribution, which suppresses the e^+p cross-section with respect to the e^-p data. The reduced cross section measurement is in good agreement with the SM prediction.

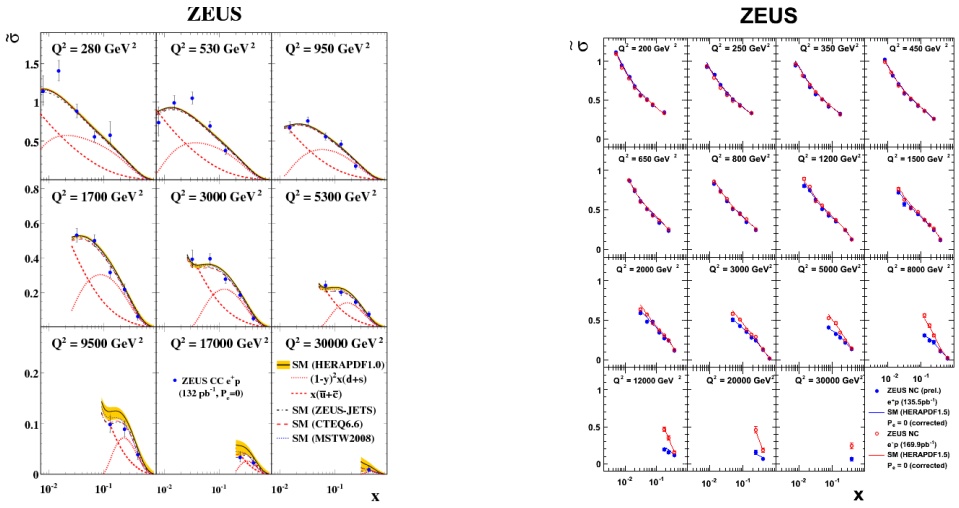

FIGURE 1. The e^+p CC DIS (left) and $e^\pm p$ NC DIS (right) reduced cross-section in as a function of x at fixed Q^2. The circles represent the data points and the curves are SM predictions using different PDFs. The dashed and dotted lines on the left plot show the contributions of $(d+s)$ and $x(\bar{u}+\bar{c})$, respectively.

Polarised CC and NC DIS

The total e^+p CC DIS cross-section, corrected to the Born level in the electroweak interaction, in the kinematic region $Q^2 > 200\ GeV^2$ was measured to be:

$$\sigma^{CC}(P_e = -0.36 \pm 0.014) = 22.9 \pm 0.82\ (\text{stat.}) \pm 0.60\ (\text{lumi.}) \pm 0.40\ (\text{syst.})\ \text{pb} \quad (4)$$

$$\sigma^{CC}(P_e = +0.33 \pm 0.012) = 48.0 \pm 1.01\ (\text{stat.}) \pm 1.25\ (\text{lumi.}) \pm 0.77\ (\text{syst.})\ \text{pb} \quad (5)$$

In Fig. 2 (right) the total e^+p CC cross-section is shown for both positive and negative values of the e^+ beam polarisation along with previous ZEUS and H1 e^+p and e^-p data[3, 4, 5, 6, 7, 8]. The results are in good agreement with the SM, which predict and increase (decrease) in $\tilde{\sigma}$ for positive (negative) e^+ polarisation. By extrapolating the total cross-section to $P_e = -1$ an upper limit on the cross-section can be converted to a lower limit on the mass of the right-handed W boson, W_R. The limits obtained are:

$$\sigma^{CC}(P_e = -1) < 2.9\ \text{pb at 95\%CL} \quad (6)$$

$$M_{W_R} > 198\ \text{GeV at 95\%CL} \quad (7)$$

The results are consistent with zero as the SM predicts.

The single differential e^+p CC cross-sections $d\sigma/dQ^2$, $d\sigma/dx$ and $d\sigma/dy$ were measured for both positive and negative e^+ beam polarisation values. The cross-sections exhibit an overall difference between the negative and positive polarisations and are consistent with the SM.

The single differential NC e^+p cross-section, $d\sigma/dQ^2$, is shown in Fig. 2 (left) for both positive and negative e^+ beam polarisation values. The cross-sections, $d\sigma/dx$ and $d\sigma/dy$ for both $Q^2 > 185\ GeV^2$ and $Q^2 > 3000\ GeV^2$ were extracted for each lepton beam polarisation as well. All single differential cross-sections are well described by

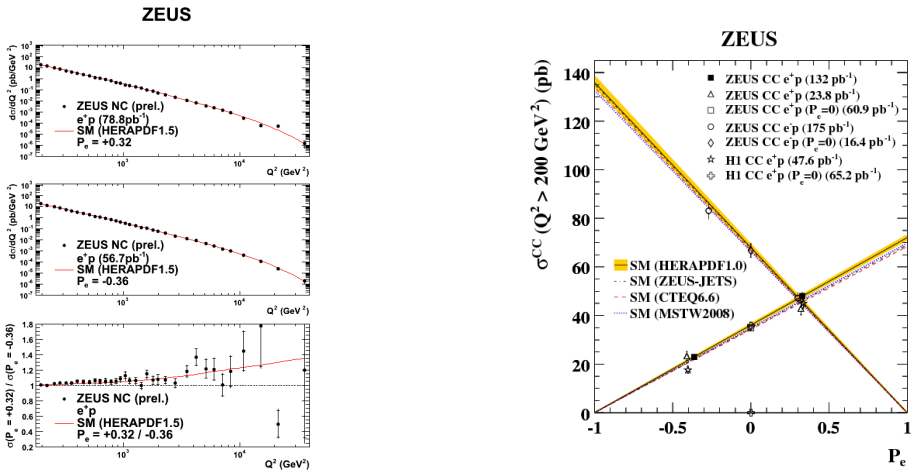

FIGURE 2. (left) Single differential NC $e+p$ cross sections $d\sigma/dQ^2$ for positive (top) and negative (middle) e^+ beam polarisation and the ratio of $d\sigma/dQ^2$ using negative and positive polarisation (bottom). The circles represent the data points and the curves show the predictions of the SM evaluated using HERAPDF1.5. (right) Total $e^{\pm}p$ CC cross sections as a function of the lepton beam polarisation, P_e.

SM predictions. The reduced cross-sections for both positive and negative e^+ beam polarisations were measured and agree well with the SM predictions. Parity violation is clearly seen in $d\sigma/dQ^2$ and the reduced cross-section.

SUMMARY

Polarised and unpolarised e^+p high-Q^2 NC and CC DIS cross-sections have been presented. The total e^+p CC cross-section at both positive and negative polarisation was shown, and is consistent with 0 when extrapolated to P_e = -1. The NC cross-section $d\sigma/dQ^2$ and polarised reduced cross-sections, clearly show parity violation at high-Q^2. The unpolarised e^+p NC reduced cross-section was presented with the previously measured e^-p cross-section showing the effect of $x\tilde{F}_3$ at high-Q^2. The results of both the CC and NC analyses are in good agreement with the SM. The newly measured NC reduced cross-sections can be used to better constrain the proton PDFs.

REFERENCES

1. ZEUS Collab., H. Abramowicz et al., Eur. Phys. J *C 70*, 945 (2010).
2. ZEUS Collab., S. Chekanov et al., Eur. Phys. J *C 62*, 625 (2008).
3. ZEUS Collab., S. Chekanov et al., Phys. Lett *B 539*, 197 (2002). Erratum in Phys. Lett. *B 552*, 308 (2003).
4. ZEUS Collab., S. Chekanov et al., Eur. Phys. J *C 32*, 1 (2003).
5. ZEUS Collab., S. Chekanov et al., Phys. Lett *B 637*, 28 (2006).
6. ZEUS Collab., S. Chekanov et al., Eur. Phys. J *C 61*, 223 (2009).
7. H1 Collab., C. Adloff et al., Eur.Phys.J *C 30*, 1 (2003).
8. H1 Collab., A. Aktas et al., Phys. Lett *B 634*, 173 (2006).